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Palmares-2 is a district managed by Landless Workers Movement on an old fazenda. After the conflict in 1997 the government recognized the settlement of 517 families. Photograph V. Gond.

RÉSUMÉ

TRAJECTOIRES DES PRATIQUES AGRICOLES PAYSANNES EN AMAZONIE

L'important corpus de recherches sur les changements d'utilisation des terres et de la couverture du sol en Amazonie brésilienne met généralement en évidence un effet significatif des systèmes de production paysanne. Cependant, l'influence des caractéristiques socio-économiques spécifiques des petits exploitants sur l'utilisation des terres et le changement de couverture des sols n'apparaît pas clairement. Afin de mieux comprendre cet aspect, une étude de cas dans la colonie de Palmares-2 en Amazonie brésilienne a été menée au niveau des ménages pour cerner l'influence de certaines variables socio-économiques sur leur utilisation des terres. Les changements d'utilisation des terres à l'échelle de l'exploitation familiale ont été analysés à l'aide d'images LANDSAT TM et SPOT disponibles pour 1986, 1992, 2001 et 2007. Ces données SIG (système d'information géographique) ont été associées aux informations recueillies lors d'une enquête auprès de 44 exploitants. L'analyse montre que les niveaux de revenus influencent positivement les taux de déforestation sur cette période, et que l'expansion des zones cultivées et des pâturages s'accroît avec le niveau d'éducation des ménages. La disponibilité de crédits non remboursables est corrélée avec l'expansion de jachères forestières. Les surface nues et/ou brûlées sont plus importantes parmi les exploitations à faible capital implantées moins durablement sur la région. Les résultats de cette étude indiquent clairement la pertinence des niveaux de revenus et d'éducation comme facteurs d'explication sur l'utilisation des terres et le changement de couverture des sols par les paysans d'Amazonie.

Mots-clés : dynamique paysagère, changements d'utilisation des terres et de la couverture des sols, lisières forestières en Amazonie, télédétection, analyse à l'échelle du foyer.

ABSTRACT

PATTERNS DEFINING SMALLHOLDER AGRICULTURAL PRACTICE IN AMAZONIA

The large body of research on land use and land cover changes in the Brazilian Amazon generally shows the significant effect of smallholder production systems. However, it is still unclear how far the specific social and economic characteristics of smallholders influence on land use and land cover changes. To shed more light on this aspect, the effects of selected socio-economic variables on land uses at the household level were investigated in a case study on the "Palmares-2" settlement in the Brazilian Amazon. Using LANDSAT TM and SPOT images available for 1986, 1992, 2001 and 2007, land use changes were analyzed on the scale of individual farms. The GIS (Geographic Information System) data were then combined with information from a survey of 44 farmers. Analysis showed that levels of income positively influenced deforestation rates over the period, and that the expansion of pastures and farmlands was significantly greater among households with a higher level of education. The availability of non-refundable credits correlated with an increase in forest fallows. Areas of bare and/or burned lands were larger among family holdings with lower capital stock that were less permanently established in the area. The findings of this study suggest that income levels and education are highly relevant factors in accounting for land-use and land cover changes among Amazonian smallholders.

Keywords: landscape dynamics, land use and land cover changes, Amazonian forest margins, remote sensing, household-level analysis.

RESUMEN

TRAYECTORIAS DE LAS PRÁCTICAS AGRÍCOLAS CAMPESINAS EN LA AMAZONIA

El amplio corpus investigativo sobre cambios en el uso de la tierra y la cobertura del suelo en la Amazonia brasileña suele poner de manifiesto un efecto significativo de los sistemas de producción campesina. Sin embargo, aún no queda claro cómo influyen las características socioeconómicas específicas de los pequeños agricultores en el uso de la tierra y de la cobertura del suelo. Para comprender mejor este aspecto, se llevó a cabo un estudio de caso en los hogares del asentamiento de palmares-2, en la Amazonia brasileña, para comprender mejor la influencia de ciertas variables socioeconómicas en su uso de la tierra. Mediante imágenes disponibles de LANDSAT TM y SPOT de 1986, 1992, 2001 y 2007, se analizaron los cambios de uso de la tierra a escala de la producción familiar. Estos datos SIG (sistema de información geográfica) se asociaron a la información recogida en una encuesta realizada a 44 agricultores. El análisis muestra que los niveles de ingresos influyeron positivamente en los niveles de deforestación durante este período, y que la expansión de áreas de cultivo y pastizales aumenta con el nivel de educación de los hogares. La disponibilidad de créditos no reembolsables está correlacionada con la expansión de barbechos forestales. Las áreas de suelos desnudos y/o quemados son mayores en las explotaciones familiares con escaso capital, cuya implantación en la región es menos duradera. Los resultados de este estudio indican claramente la pertinencia de los niveles de ingresos y de educación como factores de explicación sobre el uso de la tierra y de la cobertura del suelo de los campesinos de la Amazonia.

Palabras clave: dinámica del paisaje, cambios de uso de la tierra y de la cobertura del suelo, linderos forestales en la Amazonia, teledetección, análisis a nivel de hogar.

Introduction

Amazonian landscapes have greatly changed in the past 40 years (EVANS *et al.,* 2001; SOUZA JR., 2005), as huge areas of forest have been converted into agricultural land (CALDAS *et al*., 2007). Logging, agricultural use and burning resulted in a process of forest fragmentation and degradation (LORENA & LAMBIN, 2008). Promoted by national policies for the systematic exploration of the regions land and resources, several actors were responsible for deforestation, including loggers, mining and energy companies, agro-industries, cattle ranchers, settlers and traditional communities (ARNAULD DE SARTRE, 2006). In Brazil, cattle ranchers have strongly contributed to deforestation (MERTENS *et al*., 2002). Besides, smallholders, in particular settlers and migrants who arrived since the early 1970s on course of colonization programs and a continuously advancing road system, have also significantly contributed to land use changes (MORAN *et al*., 2004). This phenomenon is doing a continuous slowing down since 2008 but remains considerable in the forest fragmentation increasing.

Agricultural frontiers in the Brazilian Amazon are dominated by farmers and cattle ranchers from the south or the eastern part of Brazil. ARNAULD DE SARTRE (2006) observed that often after few decades, the smallholder families settling on land with poor soils and inappropriate access to public services and markets are replaced by large-scale land-owners practicing cattle ranching (LÉNA & APARECIDA DE MELLO, 2006). In more favourable contexts, where settlers have the opportunity to develop locally adapted production systems, the settled areas are gradually transformed into a mosaic of pasture, cultivated lands and different stages of secondary forests associated with agricultural fallows (EVANS *et al.,* 2001).

ZIMMERER (2004) emphasized that unpreceeding attention has been given towards understanding the household-level processes and patterning of people-forest interaction in the humid tropics. The author referred to the cultural ecology approach focusing on a selective combination of the key socio-economic and environmental dimensions that are embodied in the diverse logics and decision-making of forest using households. However, it remains fairly unclear how land use and land cover changes trajectories are linked with households characteristics.

The present exploratory study aimed at a better understanding of the influence of the Amazonian smallholders on land use and land cover changes by combining a GIS analysis of a sequence of satellite images and questionnaires applied to smallholder families living within the settlement project of Palmares-2. The study focused on two following questions: how land use and land cover have changed? How characterized the household trajectories?

Material and methods

Study area

The present study was conducted as part of a research project "Biodiversity of Amazonian Landscape, Socio-Economic Drivers and Production of Ecosystem Goods and Services – AMAZ". This project focused on the relationship among landscape organization, biodiversity and ecosystem services in Amazonia. It is a collaborative project funded by the *Agence Nationale pour la Recherche* (ANR) in France and involving Columbia and Brazil with the aim of setting up spatio-temporal indicators on Ecosystem Services to local population, in a context of fast land use and land cover changes. One study site was extracted from the global AMAZ project, *i.e.*, the settlement of Palmares-2 (figure 1).

Palmares-2 is located in Southern Pará among the largest states of Brazil and covering 1.2 million km². About 75% of the 7 million inhabitants leave in cities (IBGE, 2007). Since the first road was built in the end of the 1960 years, Pará has experi-

Figure1.
Study site of Palmares-2. A- Location of the principal deforestation front in Brazil. B- Location of the Para State. C- Location of the study site in the Para State. D- Study site of Palmares-2.

Landscape mosaic in Palmares-2. Each smallholder manages a plot of 25ha. At the first plan agricultural patchwork with fallow, sugar cane and rice is visible. On slope and remote area a degraded forest still remains.
Photograph J. Oszwald.

enced a strong land-use dynamic, characterized by rapidly advancing frontiers and strong land tenure conflicts between the traditional population, settlers, large holders, mainly cattle ranchers and companies (ARNAULD DE SARTRE, 2006). Palmares-2 had initially been a *fazenda* but was successfully invaded by the Landless Workers Movement (*Movimento dos Trabalhadores Rurais Sem Terra* or MST) in the early 1990's. After violent conflicts, in 1997 the government formally recognized the settlement of 517 families. An area of 15,850 ha was expropriated and divided between the families in regular 25 ha plots of 1,000 m by 250 m. Due to their story, three types of farmers can be identified within this population: ex *garimpeiros* (gold miners) who worked at the former El Dorado gold mine and stayed in the region after its closure; smallholders or sons of smallholders from the region who were waiting for another land (either bigger or located closer to a city); landless farmers living either in the region or in another region who wanted to own a land in order to produce for themselves.

Social and economic attributes

Social and economical variables were used to provide explanatory trends of the types of land use dynamics over time. The gained insights were then used to challenge a set of socio-economical variables potentially relevant to analyse the land use and land cover changes trajectories.

Impacts of household capitals, credit acquisition, household composition or characteristics were examined to explain recent land use and land cover changes in the study area (ARNAULD DE SARTRE *et al.*, 2009). A set of variables was selected, including: age of the household head (IDA), sex of the household head (SEX), level of studies (EST), number of children (NFI), proportion of time spent in agriculture (PCA), the father is a farmer (PAG), membership of the household head in a syndicate (POL), participation of the household head to a body of production (ORG), experience with funding (EMP), assistance technique or visit from a rural extension institution (ATE), time since occupation (DAT), available working force (UTE), refundable credits (Crb), non refundable credits (Cnrb), total credits (Ctt), salaries, daily labour incomes, non agricultural production (Rem), social policies, securities, pensions (Trf), capital for cattle ranching (Kpc) and total of the productive capital (Ktt).

Forty-four (44) farmers of Palmares-2 were selected and interviewed in June 2007, following a questionnaire considering social and economic issues about the household (table I). Questions were addressed to the family chief of each of the selected exploitations.

Land use and land cover changes

The analysis was conducted along two steps: a land use typology of the area in 2007 and a multi-temporal remote sensed analysis to assess the land use and land cover changes between 1986 and 2007.

A land use typology of Palmares-2 site was defined by an *in situ* analysis of each landscape element following different approaches. Indeed, some types were defined using agronomical descriptions (multi-stratified plantations) whereas others were based on structural features (dense forests) or dynamic indicators (exploited and burned forests). In total, 13 types were defined (dense forest (DEN), exploited forest (EXP), burned forest (BUR), swamp forest (SWA), very old fallows (VOF), old fallows (OLF), young fallow (YOF), multi-stratified plantations (MSP), pastures (PAT), pasture with shrubs (PAS), bare and/or burned lands (BAR), water bodies (WAB)). Ground Control Points aiming at covering the different landscape elements present on the study site were collected. For each point, the GPS coordinate was registered, one picture was taken in each of the cardinal directions (N, W, S and E), the landscape elements were visually described and the distance among the geo-refer-

Table I.
Main social and economic information collected through the questionnaires.

Social data	Economical data
General information on the agricultural plot	Inheritance and productive capital
Life conditions	Land use and production
Local social organization	Techniques of production
Natural resources and ecosystem services' perception	Working force
Future projects	Monetary input and output within the farm Subscribed credits and technical assistance

Table II.
Variables of land use allocation within lots for the year of reference (*i.e.*, 2007) and between the initial (*i.e.*, 1986 or 2001) and the final state (2007).

Code	Description	Calculation	Units
HA	Surface of the farm	Sum of each land cover within farm	Hectares
FOR	Forest areas	(DEN+EXP+BUR+SWA)	Hectares
MAT	Proportion of forest areas	FOR/HA	Decimal
PAS	Proportion of pastures areas	(PAT+PAS)/HA	Decimal
FAL	Proportion of fallows areas	(YOF+OLF+VOF)/HA	Decimal
BAR	Proportion of bare lands	BAR/HA	Decimal
MSP	Proportion of plantations areas	MSP/HA	Decimal
DEF	Amount of deforestation	$(FOR_{final} - FOR_{initial})$	Hectares
TXM	Rate of deforestation	DEF/HA	Decimal
Pas	Rate of changes in pastures	$(PAS_{final} - PAS_{nitial})$	Decimal
Fal	Rate of changes in fallows	$(FAL_{final} - FAL_{initial})$	Decimal
Bar	Rate of changes in bare lands	$(BAR_{final} - BAR_{initial})$	Decimal
Msp	Rate of changes in plantations	$(MSP_{final} - MSP_{initial})$	Decimal

HA: surface of the farms; FOR: forest area; DEN: dense forest; EXP: exploited forest; BUR: burned forest; SWA: swamp forest; MAT: proportion of forested areas; PAS: proportion of pastures areas; PAT: pastures; FAL: proportion of fallows areas; YOF: young fallow; OLF: old fallows; VOF: very old fallows; BAR proportion of bare lands; MSP: proportion of plantations areas; DEF: amount of deforestation; TXM: rate of deforestation; Pas: rate of changes in pasture; Fal: rate of changes in fallow; Bar: rate of changes in bare lands; Msp: rate of changes in multi-stratified plantations.

enced points and a given landscape element was estimated. Ground control points were collected along two transects and through spontaneous data sampling.

LANDSAT 5 TM and SPOT 4 images available were used for 1986, 1992, 2001 and 2007 to conduct a multi-temporal analysis of land use and land cover changes occurring in the study area over the two last decades. The spatial resolution (30 and 20 m respectively) is well adapted to characterize the landscape elements of the present study. Remote sensing acquisition during the dry season was selected to emphasis the contrast between landscape elements and to avoid nebulosity. The images were geo-referenced with the cadastral maps of the area. Radiometric calibration and atmospheric corrections were applied using the 5S program and the "ATMOSC" module from the IDRISI software (OSZWALD *et al.*, 2007). A supervised classification, maximum likelihood algorithm, was used to convert land cover into categories including forested areas, area of pastures, fallows, agricultural plantations, bare lands and water (OSZWALD *et al.*, 2010). Training areas were identified according to the field typology. The classification of the more recent images (SPOT 4, 2007) was done using available field survey data (GPS points and pictures). Training areas identification for the previous LANDSAT 5 TM images (1986, 1992 and 2001) supposed the reconstitution of the past landscape dynamics (OSZWALD *et al.*, 2011).

Spectral discrimination between selected training areas was computed using the ENVI 4.3 software (Jeffries-Matusita and Transformed Divergence test) to prevent classes overlap before processing the supervised classification. The final number of classes differs among each year, due to the heterogeneity of images resolution. Confusion matrices were calculated to assess the accuracy of the classification using the defined ground training areas for each classification. The overall accuracy was calculated by summing the number of pixels correctly assigned to classes and dividing it by the total number of pixels. Change detection statistics were used from the classification images to provide information about changes that occurred between two defined initial and final states. The classes were further identified into which pixels from the initial state image turned into the final state image. Results were compiled into a detailed tabulation of changes occurring between two classification images. A GIS overlay function linked the digital cadastral map with the four classified images of the area to generate land cover of the farms. These last data were then outputted to files readable by statistical software.

Changes in land use were derived from differences occurring in land use allocation between two years (i.e., Year $_{final}$ – Year $_{initial}$). To get an overview of the changes among the selected farms, the same calculations were done between 1986 - 2007 and 2001 - 2007. The first computation provides a global idea of the changes occurring on the farms whereas the latter illustrates the most recent changes on the properties. Remotely sensed data classifications coupled with land records were used to differentiate land use at the household scale. The two more recent classifications (2001 and 2007) were focused on as most changes in land use and land cover which were recorded for this period. The cadastre was especially used to extract the farm surface (table II).

A total of 44 farmer exploitations were covered. Selected variables included surface of the farms (HA), proportion of forested areas (MAT), proportion of pastures areas (PAS), proportion of fallows areas (FAL), proportion of bare lands (BAR), proportion of plantations areas (MSP), amount of deforestation (DEF), rate of deforestation (TXM), rate of changes in pasture (Pas), rate of changes in fallow (Fal), rate of changes in bare lands (Bar) and rate of changes in multi-stratified plantations (Msp). Farms showing a similar pattern in terms of their land use and land evolution over time were grouped. The spatial outputs of the remotely sensed data in 2001 and 2007 were used to assess the typology of farmer ownerships. Data were obtained by subtracting the farm surface area (given in ha by landscape element and by farmers ownerships) of 2001 from the more recent one of 2007.

Data processing by statistical analysis

To assess the structure of these data and because variables were in different units, a normalized Principal Component Analysis (PCA) was performed. For improving normality, variables used were log-transformed (ln) or square-root-transformed prior to PCA. The resulting classification (Ascendant Hierarchical Classification (AHC), Ward's Method) was further performed on PCA scores to establish a typology among the 44 farmers. The classification has tested by a Monte-Carlo test (OSZWALD *et al.*, 2011).

Finally the relationships between social and economical variables and changes in land uses was investigated using non-parametric Spearman correlation coefficients. A multiple linear regression model was calculated to determine the relation between social and economical variables and deforestation for the full sample (n=44). Transformed quantitative variables and qualitative (binomial) variables were treated separately.

Regarding that this study is an exploratory exercise, it was decided to applied simple linear regression than complex analysis like Statis (L'HERMIER DES PLANTES, 1976) or Act-Statis (LAVIT *et al.*, 1994) analysis developed previously (OSZWALD *et al.*, 2011) and not adapted to socio-economic analysis.

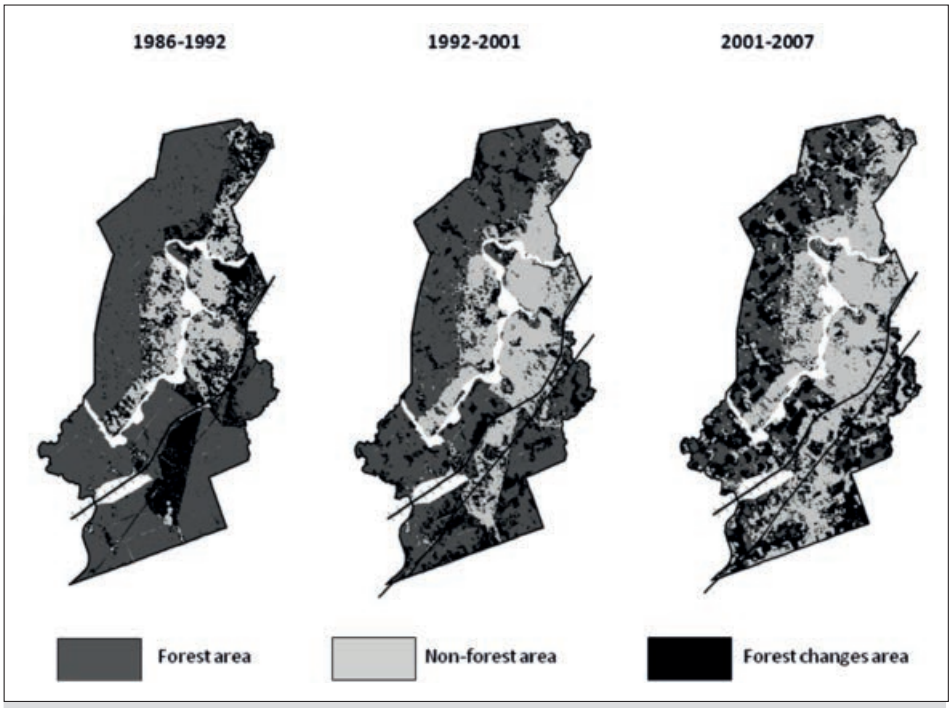

Figure 2.
Changes in Land use and Land cover in Palmares-2 from 1986 to 2007. Landscape dynamics provided for paired years 1986-1992, 1992-2001and 2001-2007. Landscape elements were grouped into forest areas (dense, exploited and burned forests) and non-forest areas (pastures, fallows, plantations, bare/burned lands and water bodies). Changes in land use over time (with a focus on forest changes) are represented by the forest change areas.

Results

Land use and land cover changes

The initial landscape was strongly dominated by dense forests. Forested areas were prominent until 2001 (figure 2). Since then, forests became more and more fragmented, and the proportion of bare lands and fallows clearly increased. Forest changes between 2001 and 2007 demonstrated a rapid progression of changes occurring at the forest margins.

Most changes in the area obviously occurred within these six years. Pattern of forest opening detected between 1992 and 2001 have consolidated until 2007. The remaining forest cover in 2007 was defined by forest area patches, which remains between the main axis of forest degradation. Furthermore, the examination of land cover in 2007 was characterized by a complex mosaic of different land uses such as advanced stages of pastures, fallows, bare lands and multi-stratified plantations, and in a smaller extent degraded forest remnants (table III).

Based on the defined land use typology and on the supervised classifications, three main dynamics were identified, assessing the complexity of the landscape evolution over time:

- A dynamic of deforestation and forest degradation, especially by burning. The analysis confirmed that forests were strongly impacted. Between 1986 and 2007 about 65% of the initially existing forests were converted into other land uses. Other land use elements strongly increased accordingly, including in particular fallows, bare and/or burned lands and pastures, for around 4500 ha.
- A dynamic of land exploitation by burning and a dynamic driven by the development of agricultural activities. The area of pastures and bare lands strongly increased and the proportion of multi-stratified plantations increased. Since their first appearance in the year 1992 their area grew fivefold.
- A dynamic of secondary growth or natural regeneration. While after deforestation, the area of older fallows increased, the proportion of young fallows remained relatively stable over time.

Household trajectories

The first PCA axis, which represented 35% of the total variability of the table describing land use reflects a dynamic of deforestation, which favours pasture establishment (with the presence of young regrowth and bare and/or burned lands which are all part of the pasture life cycle at a given time; figure 3). The dynamic reflected by the second PCA axis (20.1% of variability) is linked to agricultural activities, which do not imply further important forest degradation. Such activities might however participate to the conversion of already burned forests to plantations or pastures, and to less extent a conversion of exploited forests or bare lands. The AHC has been computed on the score of each farm of the two PCA first axis by the Ward's method.

A typology of 7 classes was established according to a 56.8 % of the variance explained and a better distribution of individuals among classes. This result highlights the different trajectories at household level. It can interpret the 7 classes of households' dynamics of land uses issued from the classification as follows (numbers correspond to figure 3):

- Class 1: Active dynamic of forest conversion (especially exploited) into a mosaic of plantations, fallows and pastures.
- Class 2: Dynamic of regrowth traducing pasture and bare lands abandon and the progression of multi-stratified plantations.
- Class 3: Development of agricultural practices with lowest impact on forested areas.
- Class 4: Recent dynamic of agricultural progression, especially pastures and multi-stratified plantations, at the detriment of the forest which was already exploited.
- Class 5: Recent dynamic of forest burning traducing a first phase of forest degradation.
- Class 6: Dynamic of forest (mainly exploited forest) conversion into multi-stratified plantations, and at a smaller extent into pastures.
- Class 7: Active dynamic of forest burning (advanced stage).

According to the DAT information, the different classes were interpreted by the first occupation time of the farm. The land cover dynamics of the classes 1 and 2 correspond to the first families that settled within the site (1998). Class 3 regroups the farms with families arrived in 1999. This

Table III.
Change in surface area of each of the defined landscape elements for the years 1986, 1992, 2001 and 2007. Changes are expressed in hectares at the global scale of Palmares-2 (changes in ha are given since the first data were recorded).

	DEN	EXP	BUR	SWA	VOF	OLF	YOF	MSP	PAT	PAS	BAR	WAB
1986	9003,8*	2698,2	0,0	0,0	0,0	1075,3	0,0	188,2	382,2	693,4	124,3	
1992	2685,3	5088,6	1085,0	0,0	0,0	1175,7	1261,6	272,5	213,8	919,7	1412,0	51,6
2001	1770,8	4457,6	1126,1	482,3	0,0	1036,3	1240,6	393,4	200,8	1037,5	1104,0	100,0
2007	451,2	1571,4	1158,4	151,9	1306,1	1640,5	899,4	1440,4	506,4	1919,4	1808,8	95,8
Change (ha)	-2234,1**	-3517,2**	-1539,9	-330,4	1306,1	464,8	-175,9	1167,9	318,2	1537,2	1115,4	-28,6

DEN: dense forest; EXP: exploited forest; BUR: burned forest; SWA: swamp forest; VOF: very old fallows; OLF: old fallows; YOF: young fallow; MSP: multi-stratified plantations; PAT: pastures; PAS: pasture with shrubs; BAR: bare and/or burned lands; WAB: water bodies.
*in 1986, no distinction between exploited and natural forest **changes since 1992

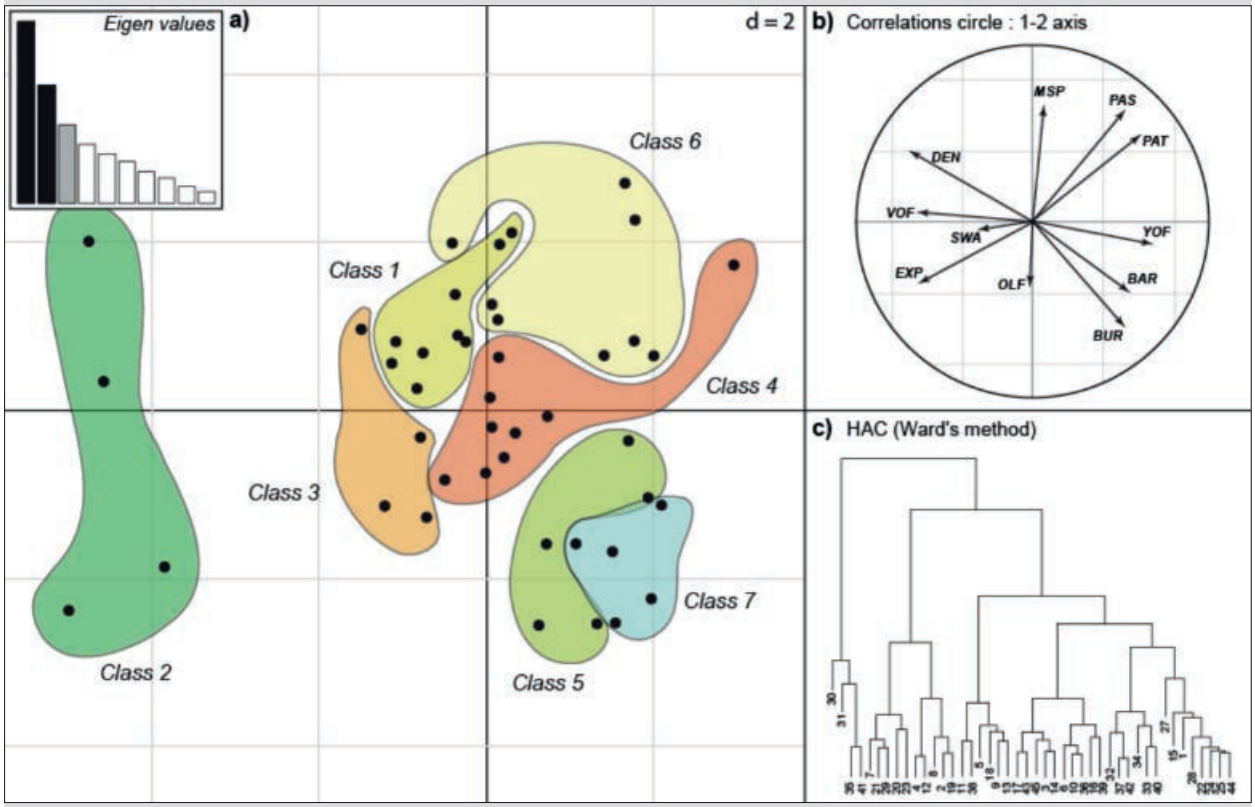

Figure 3.
a. Farms distribution in the ordination space of the land-use PCA (1-2 axis). Farms are grouped according to the typology from the AHC.
b. Correlations circle of the 1-2 axis of the PCA.
c. 7 classes are identified from the AHC (Ward's method) on the social and economic data.

group described the development of agricultural practices but having few impacts on the forested areas. Class 4 corresponds to the households being settled in 2000. This class refers to a recent dynamic of agricultural progression, where burned forests and bare lands are increasing whereas dense forests are still decreasing. The classes 5 and 6 regroup the households that were recently settled, mainly in 2001. It refers a dynamic of recent forest burning and of forest conversion into agricultural lands. Finally, class 7 corresponds to the more recent settlers who arrived in Palmares-2 in 2002. This class is represented by an active dynamic of forest burning and the progression of bare lands.

Household attributes influencing land use and land cover changes

Socio-economical characteristics of households and their spatial patterns are detailed for the seven household's types, to establish their overall profile (table IV).

To assess the driving forces of land use changes and deforestation, we searched for their correlation with social and economical variables (table V).

Deforestation rates (DEF) tended to increase with a low amount of incomes (Rem), and to less extent, a low education level (EST) or a low number of children (NFI) might have an influence. In addition, changes in forest cover (MAT) tended to increase for households with low incomes (Rem). Pasture cover (PAS) tended to progress for household with low level of study (EST), and at a smaller extent, low amount of incomes (Rem) and low available working force (UTE) might have an influence. Fallow cover (FAL) tended to progress for household with high total amount of credit (Ctt) acquired, especially non-refundable ones (Cnrb), and to less extent households heads having spent most of their lives in agricultural activities (PCA) might have an influence on fallow progression as well. Bare and/or burned lands cover (BAR) tended to progress for households with a low amount of productive capital for cattle ranching (Kpc), or with a low duration time on their properties (DAT).

No significant influence of the qualitative variables was found to explain the deforestation rate or the global land use changes between 2001 and 2007. This might be related to the more or less homogeneous pattern of households when considering this set of variables; and the heterogeneous distribution of the answer "yes" and "no".

Table IV.
Descriptive statistics based on the mean values of selected variables for each household type.

Code	n=44 means	Class 1 means	Class 2 means	Class 3 means	Class 4 means	Class 5 means	Class 6 means	Class 7 means
Social								
IDA	48.4	49.5	49.7	47.6	47.1	43.4	49.6	53.2
SEX	1.2	1.2	1.2	1.4	1	1.2	1.2	1.2
EST	3.7	1.0	6.7	2.6	5.1	5.2	2.3	4.4
NFI	5.0	6.2	5.0	6.7	4.1	5.0	4.0	2.0
PCA	0.7	0.8	0.5	0.6	0.8	0.7	0.7	0.5
PAG	1.7	1.8	1.7	1.8	1.7	1.6	1.7	1.4
POL	1.9	2	2	1.9	1.9	1.8	1.8	2
ORG	1.3	1.3	1.5	1.3	1.2	1.6	1.2	1.4
EMP	1.9	2	2	1.9	2	1.6	1.8	2
ATE	1.4	1.5	1.2	1.2	1.4	1.6	1.5	1.6
DAT	7.3	9.0	9.5	8.3	6.9	6.2	5.7	5.4
UTE	2.6	3.4	3.1	2.6	1.7	2.3	3.0	2.3
Economical								
Crb	6,838	7,300	6,625	6,584	8,125	6,250	5,667	6,900
Cnrb	2,604	2,538	2,948	2,839	2,878	1,708	2,172	2,912
Ctt	9,442	9,838	9,572	9,423	11,002	7,958	7,838	9,812
Rem	3,642	787	4,500	6,624	870	10,016	2,045	400
Trf	1,155	600	1,620	908	1,862	2,270	130	928
Kpc	5,818	6,323	16,318	5,257	2,536	6,344	4,960	3,692
Ktt	11,490	9,573	19,299	10,832	10,224	13,943	10,690	9,390
Land use allocation (2007)								
HA	26.67	25.45	26.36	23.44	24.32	25.43	25.55	26.15
MAT	0.50	0.40	0.28	0.65	0.54	0.71	0.31	0.50
PAS	0.11	0.15	0.06	0.10	0.13	0.04	0.16	0.08
FAL	0.16	0.24	0.41	0.07	0.15	0.11	0.12	0.15
BAR	0.08	0.05	0.09	0.04	0.09	0.03	0.09	0.21
MSP	0.15	0.17	0.16	0.13	0.09	0.11	0.32	0.06
Global land use changes (from 1986 to 2007)								
TXM	0.45	0.60	0.32	0.34	0.42	0.28	0.68	0.50
Pas	0.09	0.15	-0.04	0.09	0.10	0.03	0.16	0.07
Fal	0.13	0.23	0.13	0.07	0.14	0.11	0.11	0.15
Bar	0.07	-0.18	0.007	0.09	0.10	0.17	0.20	0.06
Msp	0.15	0.17	0.16	0.13	0.10	0.11	0.32	0.06
Recent land use changes (from 2001 to 2007)								
TXM	0.33	0.41	0.10	0.18	0.38	0.27	0.54	0.43
Pas	0.08	0.11	-0.10	0.08	0.12	0.04	0.14	0.07
Fal	0.10	0.18	0.14	0.03	0.13	0.10	0.04	0.15
Bar	0.05	-0.02	-0.03	0.01	0.07	0.03	0.08	0.20
Msp	0.11	0.14	0.09	0.07	0.07	0.10	0.28	0.02

IDA = Age of the household head (years); SEX = Sex of the household head (0: man / 1: woman); EST = Level of studies (years); NFI = Number of children (0-15 yrs); PCA = Proportion of time spent in agriculture (%); PAG =The father is a farmer (0: no / 1: yes); POL = membership of the household head in a syndicate (0: no / 1: yes); ORG = participation of the household head to a body of production (0: no / 1: yes); EMP = experience with funding (0: no / 1: yes); ATE = assistance technique or visit from a rural extension institution (0: no / 1: yes); DAT = Time since occupation (years); UTE = Available working force (index); Crb = Refundable credits (R$); Cnrb =Non refundable credits (R$); Ctt = Total credits (R$); Rem = Salaries; daily labor incomes; non agricultural production (R$); Trf = Social policies; securities; pensions (R$); Kpc = Capital for cattle ranching (R$); Ktt = Total of the productive capital (R$); HA = Surface of the lots (hectares) ; MAT = Proportion of forested areas; PAS = Proportion of pastures areas; FAL = Proportion of fallows areas; BAR= Proportion of bare lands; MSP = Proportion of plantations areas; TXM = Rate of deforestation; Pas = Rate of changes in pasture; Fal = Rate of changes in fallow; Bar = Rate of changes in bare lands; Msp = Rate of changes in multi-stratified plantations [Proportion and rate of changes are given in decimales].

Table V.
Correlation between the socio-economic variables and deforestation and changes in land use between 2001 and 2007 (n=44). Results express the rhô of Spearman.

Code	DEF	MAT	PAS	FAL	BAR	MSP
Economic variables						
Crb	0.1044	-0.1247	-0.0523	0.2940	0.0961	0.1161
Cnrb	0.0407	-0.0603	-0.0462	0.4127***	0.0441	-0.1979
Ctt	0.1145	-0.1354	-0.0448	0.3145**	0.1145	0.0890
Rem	-0.3304**	0.3144**	-0.2724*	-0.1776	-0.1408	0.0128
Trf	-0.1679	0.1613	-0.2074	0.0382	-0.0127	-0.1524
Kpc	-0.0345	0.0103	-0.0627	0.2517*	-0.3229**	0.0946
Ktt	-0.0325	0.0255	-0.0325	0.2105	-0.0967	-0.0643
Social variables						
IDA	0.1079	-0.1226	0.0068	0.0638	-0.0291	0.1445
EST	-0.2736*	0.2711*	-0.3286**	0.0436	0.1572	-0.3159**
NFI	-0.2744*	0.2483	-0.1574	0.0317	-0.2457	-0.0989
PCA	0.1474	-0.1567	0.1243	0.2848*	0.1066	-0.0728
UTE	-0.2069	0.2112	-0.2853*	0.0174	-0.0793	-0.0273
DAT	-0.2203	0.2000	-0.0735	0.0661	-0.4057***	0.1411

Crb = Refundable credits; Cnrb =Non refundable credits; Ctt = Total credits; Rem = Salaries, daily labor incomes, non agricultural production; Trf = Social policies, securities, pensions; Kpc = Capital for cattle ranching; Ktt = Total of the productive capital; IDA = Age of the household head; EST = Level of study; NFI = Number of children; PCA = Proportion of time spent in agriculture; UTE = Available working force; DAT = Time since occupation; DEF: Amount of deforestation; MAT: Proportion of forest areas; PAS: Proportion of pasture areas; FAL: Proportion of fallow areas; BAR: Proportion of are lands; MSP: Proportion of plantation areas. *P-value ‹0.1 **; p-value‹0.05***; p-value‹0.01.

Discussion

Methodological aspects

The study aimed to explain land use and land cover changes in Palmares-2 by analysing socio-economical characteristics of households. Land use and land cover changes were quantified. The remote sensing analysis provided a reliable basis to assess the land use and land cover changes for the study area. The deforestation impact was quantified and the landscape fragmentation was clearly shown (OSZWALD *et al*., 2010). However, the spatial resolution of pixel was not coherent over time due to the diversity of captors used (30m and 20m). Then, the quality of the four classifications increased over time (in precision and complexity).

Smallholders were classified according to the land use and land cover changes occuring on their farms. Seven classes of trajectories were identified. The number of households trajectories can be considered as too high, especially for such a small sample (n=44). However, the Huntsberger test specifies an optimal number of class for 44 samples of 7 classes (Huntsberger, 1954). The typology in 7 classes was established according to a reliable randomness of 56.8% and a better distribution of individuals among classes. It provided a wide range of detailed smallholder behavior in Palmares-2.

Land use and land cover changes

The initial landscape was strongly dominated by dense forests (figure 2). Still in 1992 forested areas were dominant until 2001. Since then, the forests became more and more fragmented, and bare lands and fallows clearly dominated. The analysis of year 2007 shows a complex mosaic of different land uses such as advanced stages of pastures, fallows, bare lands and multi-stratified plantations, and in a smaller extent degraded forest remnants.

Land-Use and Land-Cover Change (LULCC) dynamics:
- A dynamic of deforestation and forest degradation, especially by burning.
- A dynamic of land exploitation by burning.
- A dynamic driven by the development of agricultural activities.
- A dynamic of secondary growth or natural regeneration.

Forest changes between these two years consist in the progressive opening of forest margins. There is no exception: all of the forest area is concerned by such pattern (BRIANT *et al.*, 2010).

Household features influencing land use and land cover changes

Findings suggest that there is a strong linkage between the residence time of the families and the different classes of land use and land cover trajectories (GOBIN *et al.*, 2001). This suppose the evolution of a dynamic of forest burning and progression of bare lands taking place the first five years to a progressive conversion to agricultural lands. After ten years the situation will finally traduce properties characterized by a mosaic of land uses over time. According to the type of settled households, the remaining forest cover might differ from one farm to another, especially in function of the total incomes or productive capital of the household head and eventually according to their number of children or level of study (DRIGO *et al.*, 2013).

If a deforestation process could be easily pointed out as well as the conversion of an initial dense forest cover into agricultural lands (*i.e.*, pastures and plantations) on the Amazonian forest margins, one can refer to a possible sustainable use of the land over time, as it remains of prior interest for the smallholders to start to establish (SIST *et al.*, 2010). In the context of Palmares-2, some results are aiming to address the future perspective of the households stated that the majority of the interviewed farmers wish to migrate again. This observation is of major relevance as it suggests that current life conditions do not reach the want of the peoples (CRUZ *et al.*, 2011). Further research is needed in this direction, considering further variables reflecting the life condition of the smallholders as well as soil fertility and land tenure issues while proposing solutions that both match the need for forest margin consolidation and remaining forest conservation.

Within the remaining forest logging is done to produce wood for construction and wood charcoal. Photograph V. Gond.

Conclusion

Individual behaviour of migrants do influence the landscape dynamic over time. Results of this study suggested that recent land use and land cover changes occurring in Palmares-2 were linked to specific socio-economical characteristics of households. From a socio-economical point of view, some household features are the driving forces of changes in land use and land cover, especially deforestation processes. Then it may be interesting to test the possibility to characterize households typology in relation with theirs land use and land cover changes.

The final target of such analysis remains to offer the opportunity to better understand the individual trajectory and logic of migrants and their related use of the land. It is possible to assume that through a better understanding of social, economical and human-induced processes, new and better adapted policies and recommendations could be defined. The challenge will be to reproduce this kind of approach to a broader area such as Pará State. This will permit to obtain an overall view of the agricultural practices and their impacts at a larger scale.

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Bibliographical references

IBGE, 2007. Agricultural census (1995-96), Retrieved from Brazilian Institute of Geography and Statistics. [On line] http://www.ibge.gov.br

ARNAULD DE SARTRE X., 2006. Fronts pionniers d'Amazonie. Cnrs Éditions, Paris, 223 p.

ARNAULD DE SARTRE X., LAVELLE P., DOLEDEC S., HUBERT B., OSZWALD J. VEIGA I., 2009. The need for a theoretical background in building an integrated database. *In*: Proceedings of the AgSAP Conference: Integrated assesment of agriculture and sustainable development. Setting the Agenda for science and policy, p. 356-357.

BRIANT G., GOND V., LAURANCE S., 2010. Habitat fragmentation and the desiccation of forest canopies: A case study from eastern Amazonia. Biological Conservation, 143: 2763-2769.

CALDAS M., WALKER R., ARIMA E., PERZ S., ALDRICH S., SIMMONS C., 2007. Theorizing Land Cover and Land Use Change: The Peasant Economy of Amazonian Deforestation. Annals of the Association of American Geographers, 97: 86-110.

CRUZ H., SABLAYROLLES P., KANASHIRO M., AMARAL M., SIST P. (ORG.), 2011. Relação empresa/comunidade no context do manejo florestal comunitario e familiar: uma contribuição do projeto Floresta em Pé. Belém, Brazil, IBAMA, 318 p.

DRIGO I., PIKETTY M.-G., PENA D., SIST P., 2013. Cash income from community-based forest management: lessons from two case studies in the Brazilian Amazon. Bois et Forêts des Tropiques, 315: 41-51.

EVANS T., MANIRE A., DE CASTRO F., BRONDIZIO E., MCCRACKEN S., 2001. A dynamic model of household decision-making and parcel level landcover change in the eastern Amazon. Ecological Modelling, 143: 95-113.

GOBIN A., CAMPLING P., FEYEN J., 2001. Spatial analysis of rural land ownership. Landscape and urban planning, 55: 185-194.

LAVIT C., ESCOUFIER Y., SABATIER R., TRAISSAC P., 1994. The ACT (STATIS method). Computational Statistics and Data Analysis, 18: 97-119.

L'HERMIER DES PLANTES H., 1976. Structuration des tableaux à trois indices de la statistique. Thèse de 3e cycle, Université Montpellier II, France, 98 p.

LÉNA P., APARECIDA DE MELLO N., 2006. Amazonie: développement durable et dynamiques sociales. Cahiers du Brésil Contemporain, 63/64, 299 p.

LORENA R., LAMBIN E., 2008. The spatial dynamic of deforestation and agent use in the Amazon. Applied Geography, 29: 171-181.

MERTENS B., POCCARD-CAPUIS R., PIKETTY M.-G., LAQUES A.-E., VENTURIERI A., 2002. Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: the case of São Félix do Xingú in South Pará. Agricultural Economics, 27: 269-294.

MORAN E., SIQUEIRA A., BRONDIZIO E., 2004. Household demographic structure and its relationship to deforestation in the Brazilian Basin. *In*: People and the Environment. Springer, p. 61-89.

OSZWALD J., KOUAKOU J. M., KERGOMARD C., ROBIN M., 2007. Représenter l'espace pour structurer le temps: l'utilisation des SIG pour comprendre les dynamiques spatiales. Télédétection, 7: 271-282.

OSZWALD J., LEFEBVRE A., ARNAULD DE SARTRE X., THALÈS M., GOND V., 2010. Analyse des directions de changements des états de surface végétaux pour renseigner la dynamique du front pionnier de Maçaranduba (Para, Brésil) entre 1997 et 2006. Télédétection, 9: 97-111.

OSZWALD J., GOND V., DOLÉDEC S., LAVELLE P., 2011. Production d'indicateurs de changement d'occupation des sols pour le suivi des dynamiques paysagères. Bois et Forêts des Tropiques, 307: 7-21.

SIST P., DRIGO I., BARBOSA T., MAZZEI L., PIKETTY M.-G., 2010. Populations rurales et préservation de la forêt amazonienne brésilienne. Le Flamboyant, 66-67 : 42-45.

SOUZA JR. C., 2005. Mapping and Spatiotemporal characterization of degraded forests in the Brazilian Amazon through remote sensing. Santa Barbara, University of California.

ZIMMERER K., 2004. Cultural ecology: placing households in human-environment studies – the case of tropical forest transitions and agrobiodiversity change. Progress in Human Geography, 28 : 795-806.